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Science, technology, and the Cold War

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History has seen many ferocious ideological conflicts, including the Crusades and the sixteenth-century Wars of Religion. What made the Cold War peculiarly dangerous and ubiquitous was the power of modern technology, most obviously nuclear weapons. But other new technologies were equally central: out of a vast range this chapter looks particularly at transistors, satellites, and computers. On both sides, the Cold War spawned massive military-industrial complexes, but the American version was much better integrated with the larger economy and society. The Soviet system, by contrast, suppressed the civilian economy and restricted the flow of information. In the short term, this enabled the Soviet Union to punch above its economic weight as a military power. By the 1980s, however, technology and information had become the Soviet Achilles heel.

The varieties of 'Big Science'

'When history looks at the twentieth century', wrote the American physicist Alvin Weinberg in 1961, 'she will see science and technology as its theme; she will find in the monuments of Big Science', such as huge rockets and particle accelerators, 'symbols of our time just as surely as she finds in Notre Dame a symbol of the Middle Ages.'[1]

Weinberg helped popularise 'Big Science' as a catchphrase of the 1960s. Although hard to define precisely, the term signified a combination of big money, big equipment, and big teams, focused on a few key areas of activity and fusing pure science, technology, and engineering. Big Science was not an entirely postwar phenomenon – in the 1930s, some German and American companies already had large industrial research departments – but it took the

1 Alvin M. Weinberg, 'Impact of Large-Scale Science on the United States', *Science*, 134, 21 July 1961, 161.

Second World War and the Cold War to introduce the crucial element of big government. The state became the pre-eminent patron of scientific research largely because of the new imperatives of national security, and this was particularly true for the two superpowers. The locus of research varied: the Soviet Union, France, and West Germany favoured specialist institutes, whereas the United States and Britain kept it mostly within government laboratories and universities (thereby encouraging a symbiosis of teaching and research). In these varied forms, the governmental-industrial-academic complex was the motor of Big Science for most of the Cold War era.

This chapter centres on the United States and the Soviet Union. Before 1940, federal funding for research and development (R&D) was small, and mostly agricultural. All this changed with the Second World War, when the US government mobilised the nation's universities and R&D labs on a contract basis. The atomic bomb became the most celebrated project, but its price tag of some $2 billion was two-thirds of that for radar ($3 billion). The technological spin-offs from the latter were immense: as we shall see, the transistor had as big an effect on the Cold War as the bomb. Equally important, thousands of scientists had been moved by government from nuclear and particle physics – the 'sexy' subjects of the 1930s – into solid-state physics and related fields.

The US government's Office of Scientific Research and Development was wound up at the end of the war, but the valedictory report by its head, Vannevar Bush, left a marker for the future. Entitled *Science: The Endless Frontier*, it established the idea that 'basic research' was 'the pacemaker of technological progress', for which much of the future funding had to come from Uncle Sam.[2] The 'laboratories of America have now become our first line of defense', Secretary of War Robert Patterson declared in October 1945. Each service sponsored a plethora of big R&D projects in universities and industry, even before the Soviet atomic test and the Korean War in 1949–50 made the Cold War a paramount issue of national security. By 1956, defence projects constituted more than half of all spending on industrial R&D in the United States.[3]

The humiliation of the Soviet Sputnik launch in 1957 pushed American funding to new levels. Aeronautics and electronics were the prime beneficiaries,

2 Vannevar Bush, *Science: The Endless Frontier – A Report to the President on a Program for Postwar Scientific Research, July 1945* (Washington, DC: National Science Foundation reprint, 1960), 19.

3 Paul Forman, 'Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940–1960', *Historical Studies in the Physical and Biological Sciences*, 18 (1987), esp. 152–53 and 156.

but many areas of science were transformed, among them oceanography and materials science. Although direct military sponsorship of R&D became relatively less important after 1960, it remained at roughly the same level in real terms through the 1970s and 1980s. What was new was the emergence of other federal funders such as the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and especially the National Institutes of Health (NIH), which accounted for about half of federal R&D by the 1970s. Most of their sponsorship was for national security and status in a broad sense, and it resulted in other vast programmes in the 1980s, such as the $2 billion Hubble Space Telescope. Whereas federal spending had amounted to only 1 per cent of gross national product (GNP) in 1929, the proportion was nearly 17 per cent in 1953 – much of it defence-related.[4]

But although government funding shaped whole areas of scientific research in the United States, several qualifications must be made. First, scientists were not mere servants of the military. Shrewd scientist-politicians like Frederick Terman at Stanford and John Slater at the Massachusetts Institute of Technology (MIT) were able to advance their own research goals by packaging them attractively for military-industrial sponsors. Secondly, there was extensive, if erratic, civilian spin-off from military-funded research. Co-operation between scientists and business on government projects spawned the Stanford Industrial Park (1951), the precursor of Silicon Valley, and the network of high-tech companies around MIT's labs along Route 128 around Boston. By the 1960s, the federal government was also spreading its funding more broadly to start-up companies as well as to established giants like Lockheed or International Business Machines (IBM). This highlights the third and most significant point: the United States had a thriving capitalist economy, geared predominantly to consumer markets at home and abroad. Defence industries became an important part of the domestic economy, often pioneering innovation, but they never dominated. By the mid-1950s, the United States, with only 6 per cent of the earth's population, was producing and consuming over one-third of its goods and services. GNP rose by half in real terms during the decade. Even in the rundown mining area of Harlan County, Kentucky – one of the United States' poorest areas – 67 per cent of homes had a television and 59 per cent had a car.[5] This was a far cry from the Soviet Union, which boasted the world's most enormous yet narrowest military-industrial-academic complex.

4 William E. Leuchtenburg, *A Troubled Feast: American Society since 1945* (Boston: Little, Brown, 1973), 47.

5 James T. Patterson, *America's Struggle against Poverty, 1900–1981* (Cambridge, MA: Harvard University Press, 1981), 80.

State control of science was not invented by the Bolsheviks, who built on tsarist practice. Their structure of research institutes also drew on elitist German models. What was novel about Stalinist Big Science was the *extent* of state control and of elite isolation. The regime needed scientific innovation to enhance national wealth and security; yet such innovation depends on unfettered critical discussion of a sort that is potentially subversive in a closed society. This was Stalin's dilemma, and it helps explain why so many Soviet scientists and engineers were purged and imprisoned. It also dictated the deliberate physical segregation of Soviet scientists in research institutes and special closed cities of the 'white archipelago' of nuclear plants. In consequence, Soviet physics was 'an island of intellectual autonomy in the totalitarian state . . . the closest thing to civil society in the Stalinist regime' – from whose ranks dissidents such as Andrei Sakharov would eventually spring.[6]

Tight controls on civilian consumption enabled the Soviets to concentrate on military production. And centralised control of manpower and resources facilitated major projects such as aeronautics, space, nuclear weapons, and hydro-electric power. In these areas, the Soviet Union was able to match the United States. But there was a double price to be paid for segregating scientists. First, they were cut off from university teaching, with the result that Soviet science had to live off the intellectual capital of men educated in the era of relative international openness before the Bolshevik Revolution. Those scientists retired and died in the 1960s and 1970s, to be replaced by juniors formed in a Stalinist mould that excluded whole areas of science as bourgeois, cosmopolitan fallacies. Genetics was the most notorious example, but cybernetics and quantum physics were also under a cloud in the late Stalin years. Secondly, scientists were also isolated from ordinary industry. In 1982, only 3 per cent of Soviet research scientists with the *kandidat* degree (roughly equivalent to an American doctorate) were employed by industrial plants. Moreover, the lack of a thriving consumer economy full of opportunities for entrepreneurship reduced the scope for commercial development of military-funded innovations, particularly in the critical sectors of computers and information technology in general.[7]

6 David Holloway, *Stalin and the Bomb: The Soviet Union and Atomic Energy* (New Haven, CT: Yale University Press, 1994), 363.

7 Loren R. Graham, *Science in Russia and the Soviet Union: A Short History* (Cambridge: Cambridge University Press, 1993), 180. More generally, see two related volumes of essays: Ronald Amann, Julian Cooper, and R. W. Davies (eds.), *The Technological Level of Soviet Industry* (New Haven, CT: Yale University Press, 1977), and Ronald Amann and Julian Cooper (eds.), *Industrial Innovation in the Soviet Union* (New Haven, CT: Yale University Press, 1982).

'The Cold War', writes science historian Nikolai Krementsov, 'gave defining meaning to two systems of Big Science, two mutually isolated but interdependent creatures, each almost unthinkable without the other.'[8] In the McCarthyite 1950s, American Big Science had many similarities with Soviet practice: major government institutions like Los Alamos formed their own 'white archipelago'. But, overall, the United States was a far more complex economy and a much more open society. Civilian spin-off from military-funded research was frequent and extensive, and most new technologies gradually freed themselves from the handcuffs of Uncle Sam – the transistor and the computer being notable examples. In short, although both superpowers undertook Big Science on a massive scale, the technologies that shaped the late twentieth century were the products of capitalism, not Communism, and that proved enormously important for the outcome of the Cold War.

Transistors and the revolution in electronics

The computer revolution offers a good example of how a vital technology fuelled the Cold War, but also developed a trajectory and momentum of its own, particularly in the capitalist West.

Electronic computers were another spin-off from the Second World War. They were made possible by expertise and technology from the vast British and American radar projects; they were made necessary by the massive and speedy mathematical calculations required in technowar. By the end of 1943, the British government was using an electronic calculator, Colossus, to crack German ciphers at its Bletchley Park code-breaking centre. The first stored-programme computers were built and tested in England in 1948–49. These pioneering machines were essentially mathematical instruments, designed for complicated calculations. During the 1950s, however, their successors were developed as massive data-processors, to replace desk calculators or punched-card systems. They were produced in a big way in the United States by Remington Rand and especially International Business Machines Corporation (IBM) which, by 1964, accounted for 70 per cent of the worldwide inventory of computers, with a value totalling $10 billion.[9]

8 Nikolai Krementsov, *Stalinist Science* (Princeton, NJ: Princeton University Press, 1997), 290.

9 Emerson W. Pugh, *Building IBM: Shaping an Industry and Its Technology* (Cambridge, MA: MIT Press, 1995), 296.

In part, IBM won out through superior customer support and heavy investment in R&D. But government contracts, particularly for the military, made a crucial contribution to establishing IBM as the industry's giant in the quarter-century after the Second World War. Over half of IBM's revenues from electronic data processing in the 1950s came from its analog guidance computer for the B-52 bomber and from the Semi-Automatic Ground Environment (SAGE) air defence system – at around $8 billion, the largest and most expensive military project of the 1950s. In 1955, about 20 per cent of IBM's 39,000 American employees were working on it.[10]

Yet SAGE is a neglected Cold War story.[11] After the Soviet nuclear test in 1949, US Air Force (USAF) planners were alarmed at the vulnerability of the United States to Soviet air attack. To co-ordinate information from radar all over North America, a vast and very sophisticated computing system was needed – operating in real time, extremely reliable, and around the clock. The USAF turned first to MIT, establishing a special research programme there in 1951, which became the famous Lincoln Laboratory near Route 128. Once MIT had designed a feasible system and tested a prototype on Cape Cod, south of Boston, IBM won the contract to build and run the computers for the whole system. The first SAGE direction centre became operational in July 1958, but the whole system was not fully deployed until 1963 – involving twenty-four separate centres, each with two identical computers to permit servicing and prevent any system collapse. Each computer had 60,000 vacuum tubes and occupied an acre of floor space. Later, the vacuum tubes were replaced with magnetic cores, vastly enhancing speed and reliability. SAGE thereby pioneered the random-access core memory that within a few years was routine in all commercial computers. Apart from the financial benefits, SAGE also gave thousands of IBM engineers and programmers their basic training in the business. The experience gained was fully utilised when IBM was asked in 1957 to design a computerised reservations system for American Airlines. Little wonder that Thomas J. Watson, the company's head, claimed: 'It was the Cold War that helped IBM make itself the king of the computer business.'[12] Not until 1959 did IBM's revenues from commercial

10 Kenneth Flamm, *Creating the Computer: Government, Industry, and High Technology* (Washington, DC: Brookings Institution Press, 1988), 82–90.

11 On SAGE, see the special issue of *Annals of the History of Computing*, 5,4 (October, 1983), 319–403, and Paul Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, MA: MIT Press, 1996), ch. 3.

12 Thomas J. Watson, Jr., and Richard Petre, *Father and Son, & Co.: My Life at IBM and Beyond* (London: Bantam Press, 1990), 230–33.

electronic computers exceed those from SAGE and other military computing projects.[13]

In April 1964, IBM unveiled its System 360 'family' of computers and peripherals, all using the same software. By the end of the decade, it had captured three-quarters of the world market for mainframe computers. This great leap forward in technology was partly the result of refining the magnetic core memory developed for SAGE. But even more important was the revolution in electronics that made possible, first, the transistor and, then, integrated circuits. Again, the Cold War proved a critical catalyst.

The vacuum tubes used in early televisions and computers were large, fragile, and expensive. But a substitute emerged from wartime work on radar, where electronic tubes could not be used for microwave detection – hence the development of crystals such as germanium and silicon as semiconductors. After the war, Bell Laboratories – the research arm of the telecommunications giant AT&T – employed this wartime knowledge and many radar scientists in the search for a solid-state amplifier. At the end of June 1948, Bell unveiled a prototype called 'the Transistor', but the announcement was overshadowed by the start of the Berlin blockade. A brief story was relegated to the back of the *New York Times* under the heading 'News of Radio'.[14]

Although the first transistor radios were on sale by 1954, the new technology took time to catch on. The industry gradually moved from craft methods – rows of women workers using tweezers – to mass production and, in raw materials, from germanium to the more robust silicon. By 1960, the platform for a commercial industry had been built. But the industry would not have reached that point without military assistance. The transistor was hugely attractive to the armed forces because they needed reliable, lightweight guidance and communications systems in ships, planes, and guided missiles. By 1953, the US military was funding half of Bell Labs' R&D in transistors. Even more important, it provided large and secure markets. The proportion of US semiconductor production for military use rose from 35 per cent in 1955 to a peak of nearly 48 per cent in 1960. In 1963, transistor sales to the military were worth $119 million, to industry $92 million, and only $41 million to the consumer.[15]

By the 1960s, the military was spreading its money more widely, to smaller, specialist firms such as Fairchild Semiconductor and Texas Instruments. These

13 Pugh, *Building IBM*, 326, Appendix D. 14 *New York Times*, 1 July 1948, 46.

15 Ernest Braun and Stuart MacDonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics*, 2nd ed. (Cambridge: Cambridge University Press, 1982), 80.

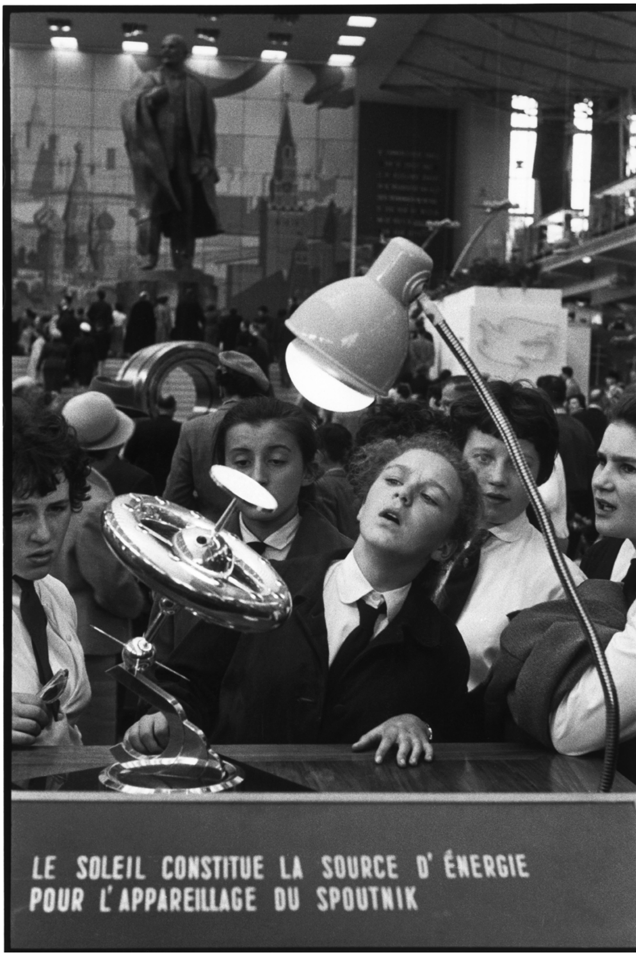
companies were another sign of the porous nature of the military-industrial-academic complex in the United States (unlike the Soviet Union), and they were also the motor for the next phase in solid-state technology. Between them, Texas and Fairchild pioneered miniaturisation, replacing separate transistorised components linked in circuits with a single integrated circuit in one piece (or chip) of germanium. The first chips were marketed in 1961. By the end of the decade integrated circuits had become the norm in electronic components such as digital watches, which flooded the consumer market in the 1970s. But once again, Cold War funding and demand helped at the crucial start-up stage – until 1967 the US military was taking over 50 per cent of chip production, much of it for the new space race.[16]

Satellites and the revolution in communications

Despite more or less keeping up with the United States in testing nuclear weapons, the Soviets had lagged far behind in delivery systems. By the late 1950s, the USSR was threatened not only by the B-52 intercontinental bombers of the United States' Strategic Air Command, but also by aircraft and medium-range missiles located in Britain, Germany, and other allied countries. By contrast, the United States seemed immune from attack – that is, until Sputnik. On 4 October 1957, a Soviet R-7 missile from the Kazakh desert launched the world's first artificial earth satellite. Although only the size of a grapefruit, its eerie 'ping-ping' became familiar to radio listeners around the world. On 3 November, another satellite put a dog, Laika, into space for ten days. On the fortieth anniversary of the Bolshevik Revolution, a few days after this second launch, Soviet leader Nikita Khrushchev declared that the Soviet Union would surpass the United States in per capita output within fifteen years.

Sputnik was a huge blow to American technological pride. In September 1958, the National Defense Education Act authorised $1 billion over seven years in loans, fellowships, and grants to 'help develop as rapidly as possible those skills essential to the national defense'.[17] The following month saw the start of operations for a lavishly funded civilian National Aeronautics and Space Administration. Initially, the United States floundered. Its highly

16 *Ibid.*, 98.
17 Barbara Barksdale Clowes, *Brainpower for the Cold War: The Sputnik Crisis and National Defense Education Act of 1958* (Westport, CT: Greenwood Press, 1981), 162.



27. A model of Sputnik in the Soviet pavilion at the Brussels World's Fair, 1958: briefly, the Soviet leaders could trumpet the superiority of their system.

publicised satellite launch on 6 December 1957 got a few feet off the ground from Florida's Cape Canaveral before the US Navy's giant Vanguard rocket sank back to earth in a ball of fire. Pictures of 'Flopnik' were beamed around the world. The Soviet programme, masterminded by Sergei P. Korolev, maintained its lead by launching the first satellite to orbit the moon on the second anniversary of Sputnik in October 1959. And, on 12 April 1961, Iurii Gagarin became the first man to orbit the earth. The handsome young cosmonaut, with his telegenic smile, became a national and international hero.

Soviet 'firsts' in space convinced many around the world that, just as Khrushchev boasted, the Soviet Union had eclipsed the United States technologically. But the reality was very different. The day after Gagarin was received in triumph at the Kremlin, Sir Frank Roberts, the British ambassador in Moscow, had to drive to Leningrad – seven hundred kilometres away. There were only two filling stations en route. At the one where Roberts stopped, the automatic pumps had failed. While the staff filled his Rolls Royce by hand, Roberts reflected on Gagarin's flight and savoured the irony.[18] The story graphically illustrated the civilian price for Soviet Big Science: rockets beat the automobile hands down.

American humiliation in the space race in 1957 had more to do with rivalry between the army and navy than between the superpowers. Once resources and energies were focused in a single programme, the United States caught up. And the space race provided a massive new market for transistors and then chips. By January 1962, the United States had launched sixty-three payloads into space, the Soviet Union only fifteen.[19] Although Soviet and American publicists concentrated on the human cargoes, what really mattered in the Cold War were the satellite launches. Although U-2 overflights of the Soviet Union came to an end in May 1960 after Gary Powers was shot down over the Urals, from August, the Discoverer satellite program started to provide even better intelligence. The first twenty-pound roll of film captured a million square miles of the Soviet Union. This, said one analyst from the US Central Intelligence Agency later, was 'more coverage in one capsule than the combined four years of U-2 coverage'.[20]

The Soviets soon followed suit, however. Between 1957 and 1989, a total of 3,196 satellites and space vehicles were launched. Of these, 2,147 were Soviet and 773 American; Japan was in third place with a mere 38. About 60 per cent of the launches were military, and one-third were 'spy satellites' for photo reconnaissance.[21] The superbly detailed intelligence thereby gained enabled each superpower to keep watch on the other, and provided essential re-assurance for their more stable relationship after the Cuban crisis of 1962.

18 Jeremy Isaacs and Taylor Downing, *Cold War* (London: Bantam Press, 1998), 162.

19 Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 272.

20 Dino Brugioni, quoted in Christopher Andrew, *For the President's Eyes Only: Secret Intelligence and the American Presidency from Washington to Bush* (London: HarperCollins, 1995), 250.

21 These and other figures for satellites from Desmond King-Hele et al., (eds.), *The RAE Table of Earth Satellites 1958–1989*, 4th ed. (Farnborough, UK: Royal Aircraft Establishment, 1990), iv–vii.

In January 1967, they signed the Outer Space Treaty, which banned 'nuclear weapons or any other kinds of weapons of mass destruction' from space, the moon, and 'other celestial bodies'. Although both governments continued research into anti-satellite weapons as a safeguard, their consensus on the peaceful use of space was not breached during the Cold War.

Because space was not a battleground, satellite technology could also be used for civilian benefit. Again, the military pioneered the way. The US Army's Tiros series of weather satellites, first launched in 1960, transformed meteorological information and prediction. When Hurricane Camille hit Florida in August 1969, it caused $1.5 billion in property damage, but only 260 lives were lost because of evacuation thanks to satellite early warning. The Soviets had their own meteorological system operating by the end of the 1960s. One of the biggest spin-offs from satellites was in navigation systems. These were pioneered in the 1960s for military use, and full development occurred only at the end of the Cold War. But, in December 1993, the first Global Positioning System became operational, with twenty-four satellites, transforming the movement of freight and people.

The greatest effect of satellites, however, was on communications. In October 1945, Arthur C. Clarke predicted that versions of the V-2 rockets that Germany had rained down on London could be used to launch 'artificial satellites' which, properly positioned, could relay radio and television coverage to the whole planet.[22] Clarke would later make his name with science-fiction classics such as *2001: A Space Odyssey*, but his visions were grounded in wartime service on radar. Yet, even he did not expect them to be realised for at least fifty years; in fact, the first communications satellite, Score 1, was launched by the US Army Signal Corps in December 1958, little more than a year after Sputnik. As Clarke admitted in the early 1990s, 'the political accident of the Cold War is really what powered our drive into space. If it had been a peaceful world, we might not even have the airplane, let alone landed on the moon.'[23]

In 1960, NASA offered to launch private satellites at cost, provided clients shared their results. The communications giant AT&T quickly signed up, and on 10 July 1962 Telstar 1, a mere 88 centimetres in diameter, accomplished the first trans-Atlantic television transmission from a ground station in Maine to stations in Britain and France. In November 1963, John F. Kennedy's funeral

22 Arthur C. Clarke, 'Extra-Terrestrial Relays: Can Rocket Stations Give World-Wide Radio Coverage?', *Wireless World*, 51 (October 1945), 304–08.

23 Interview quoted in William J. Walker, *Space Age* (New York: Random House, 1992), 218.

was beamed live to Europe, Japan, and parts of North Africa. Nine months later, in August 1964, the Olympic Games in Tokyo were broadcast live across the Pacific. In that same month, the International Communications Consortium (Intelsat) was established by fourteen countries. By 1975, Intelsat had eighty-three members – half the United Nations.

The Cold War was profoundly affected by satellite broadcasting. Historic turning points such as President Richard M. Nixon's China odyssey in 1972 and the fall of the Berlin Wall in 1989 derived their international impact from live television images. But although satellites internationalised television news, they also made it more intensely national by opening up all areas of a vast country to official television. The Soviet Union was the first to grasp the potential. Its Ekran satellites, combined with some 3,000 ground stations, spread national television across Siberia and the Soviet Far East. By the mid-1980s, over 90 per cent of the population could receive at least one channel.[24] National satellites subsequently enabled some of Asia's huge developing countries, particularly China, to enlarge their national television network. Although satellites served a similar function in large Western countries – Telesat Canada opened up the country's remote north – it was particularly in authoritarian states that its role in nation-building was significant. Television became the favoured 'transmission belt' for conveying government propaganda to the masses, though most people became inured to yet more programmes about the heroism of labour or the latest five-year plan. In the United States, there was, unusually, no government broadcasting system, but the three big American networks imposed an increasingly monochromatic diet. On both sides of the divide, the Cold War depended for much of its potency on the relatively controlled nature of the mass media. The cable revolution in television news, allowing much greater diversity of information and debate, did not really take hold until after the Cold War was over. In 1965, the three big American networks took 90 per cent of the prime-time audience. In 1995, their share was still 60 per cent.[25]

Satellites, therefore, internationalised the mass medium of television, but also nationalised it during the Cold War era. Yet, they were only part of a larger revolution in telecommunications in the postwar world.

24 Robert W. Campbell, 'Satellite Communications in the USSR', *Soviet Economy*, 1 (1985), 315–16.

25 Joseph R. Dominick, Barry L. Sherman, and Gary A. Copeland, *Broadcasting/Cable and Beyond: An Introduction to Modern Electronic Media*, 2nd ed. (New York: McGraw-Hill, 1993), 68, 125.

In most European countries, post, telephone, and telegraph (PTT) services were under the control of a government department, and this model had been exported to the developing world. PTT services, even more than television, were essential to national communications and vital for national security. Control of them also enabled governments to play 'Big Brother' through mail censorship and phone tapping. Such surveillance was routine in Communist or authoritarian states, but most Western governments during the Cold War also kept PTT services under close control. The Federal Bureau of Investigation under J. Edgar Hoover was notorious for its extensive phone tapping. The United States did not have a government-run phone network, but the American Telephone and Telegraph Company had enjoyed an effective monopoly since the 1930s. It operated the only long-distance network, its subsidiary Western Electric made most of the phones and equipment, and its research arm, Bell Labs, developed the essential technologies. The survival of this monopoly, despite anti-trust actions by the US Justice Department, was the result of the Pentagon's need for a single organisation with all these capabilities that was at the beck and call of the US government. In the late 1940s, the US military accounted directly for 15 per cent of Bell Labs' budget.[26] In 1970, AT&T was the largest corporation in the world. It had $53 billion in assets, generated $2.5 billion in net income, and employed over 1 million workers.[27]

Demand for international communications also increased with the growth of world trade and travel. In 1956, the first trans-Atlantic telephone cable (TAT 1) was inaugurated. Two cables ran 2,000 miles from Scotland to Newfoundland, providing thirty-five phone circuits in each direction. Three years later, TAT 2 linked Newfoundland with France. These coaxial cables were a vast improvement on shortwave radio for international phone calls, but they in turn were overtaken by satellites. Intelsat I ('Early Bird'), launched in 1965, had circuits for 240 simultaneous calls; Intelsat IV (1971) boasted 2,000. Over this period, the cost of each circuit fell from around $20,000 a year to $700.[28] In due course, optical fibres – with their vast bandwidth and complete freedom from electromagnetic interference – offered an even better alternative.

26 Daniel J. Kevles, 'Korea, Science, and the State', in Peter Galison and Bruce Hevly (eds.), *Big Science: The Growth of Large-Scale Research* (Stanford, CA: Stanford University Press, 1992), 314.

27 Peter Temin, with Louis Galambos, *The Fall of the Bell System: A Study in Prices and Profits* (Cambridge: Cambridge University Press, 1987), 10.

28 Günter Paul, *The Satellite Spin-Off: The Achievements of Space Flight*, transl. by Alan Lacy and Barbara Lacy (New York: Robert B. Luce, 1975), 53–58.

The first trans-Atlantic optical cable, TAT 8, was opened in December 1988. Capable of handling 40,000 simultaneous phone conversations, the system doubled existing trans-Atlantic cable capacity and constituted a serious rival to satellites.[29] But this was not until the very end of the Cold War.

In most developed countries, telephone coverage soon became extensive: half the households in the United States had a phone in 1946, 90 per cent in 1970. In West Germany, the proportion rose from 12 per cent to 75 per cent between 1960 and 1980.[30] But, in 1985, the Soviet Union had only about one-sixth the number of household phones that the United States had, despite having 18 per cent more people. There were only 1.7 billion intercity calls, compared with 37 billion in the United States. Two-thirds of the transmission network was cable, not much of it coaxial, and, unlike the West, communications satellites carried very little civilian phone traffic. They were used mainly for Soviet television and, from the late 1970s, to transmit copies of Moscow newspapers across the country for local printing and distribution. This again illustrated the priorities of the regime.[31] The pattern was similar across the Soviet bloc, where phone penetration averaged about 12 lines per 100 people in the late 1980s, compared to the European Community average of 37. Poland and East Germany were particularly backward.[32] As in the USSR, equipment was outmoded, reception poor, and waiting lists long. Whereas in the West the emphasis was increasingly on consumerism, the Communist bloc's philosophy remained one of control.

This contrast was accentuated in the mid-1980s by the deregulation of PTT giants in the West, starting with AT&T and followed by the British and Japanese national phone systems. Motivation for these changes was complex, including pressure for more investment and the clamour of potential rivals, but at root the whole rationale of telecommunications was changing. The emphasis was no longer on providing a basic public service but on answering the needs of the new 'information society'. Improved communications were

29 John Bray, *The Communications Miracle: The Telecommunication Pioneers from Morse to the Information Superhighway* (London: Plenum Press, 1995), 289.

30 Eli Noam, Seisuke Komatsuzaki, and Douglas A. Conn (eds.), *Telecommunications in the Pacific Basin: An Evolutionary Approach* (New York: Oxford University Press, 1994), 25–26.

31 Robert W. Campbell, *Soviet and Post-Soviet Telecommunications: An Industry under Reform* (Boulder, CO: Westview, 1995), esp. 15, 22, 95–102.

32 Jürgen Müller and Emilia Nyevrikel, 'Closing the Capacity and Technology Gaps in Central and Eastern European Telecommunications', in Bjorn Wellenius and Peter A. Stern (eds.), *Implementing Reforms in the Telecommunications Sector: Lessons from Experience* (Aldershot, Hants: Avebury, 1996), 354–59.

deemed essential to transmit the vast amounts of data being generated by modern computers.

Computers and the revolution in information

It was in the computer that the chip found its real home.[33] Microprocessors designed originally for electronic calculators were adapted as computer memory, cutting the size and price of computers dramatically. In this technological revolution the military played no part. Far more important was the Californian youth culture of the Vietnam War era, in crucibles such as the Homebrew Computer Club at Menlo Park, on the edge of Silicon Valley. The first Apple computers – not much more than crude circuit boards – were assembled in the family garage of Steve Jobs, a college drop-out. But once Apple had democratised computer power, IBM commandeered it for corporate capitalism. Its personal computer (PC), launched in August 1981, used chips from Intel and a software-operating system from a small Seattle company called Microsoft. IBM's PC put the imprimatur of one of the world's greatest corporations on the personal computer; it was no longer a hobbyist's toy. Other companies rushed to produce 'IBM-compatible' machines, most of them sold with MS-DOS, which, by the mid-1980s, was the dominant operating system in the business and the source of half of Microsoft's annual revenue.[34] PC sales doubled from 724,000 in 1980 to 1.4 million in 1981, and doubled again to 2.8 million in 1982.[35]

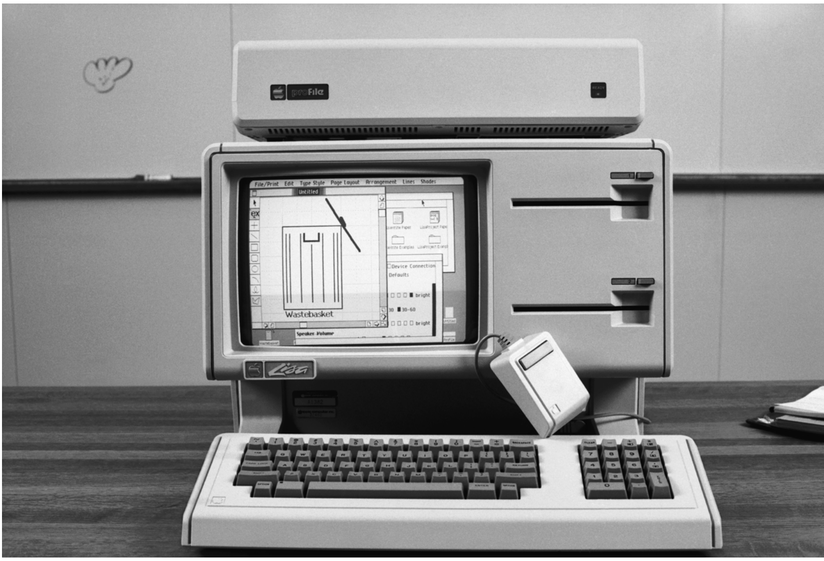
In consequence, the US computer market was transformed. In 1978, computer sales were worth $10 billion, of which about three-quarters were mainframe. By 1984, the figure was over $22 billion, of which less than half was mainframe. The computer was moving from government and corporations into small businesses and the home. In the process, the industry became much less reliant on government patronage. The federal share of computer-related R&D expenditure fell from two-thirds in the 1950s to one-fifth by the 1980s.[36] Without the Cold War, electronics and computing would not have developed so quickly and dramatically in the United States. But the strength of American corporate capitalism and the relative openness of American society

33 On this, see especially Martin Campbell-Kelly and William Aspray, *Computer: A History of the Information Machine* (New York: Basic Books, 1996), ch. 10.

34 Daniel Ichbiah and Susan L. Knepper, *The Making of Microsoft: How Bill Gates and His Team Created the World's Most Successful Software Company* (Rocklin, CA: Prima Publishing, 1991), 93.

35 *Time*, 3 January 1983, 4.

36 Figures from Flamm, *Creating the Computer*, 238, 253.



28. Apple computer, 1983: Apple democratised computer power and demonstrated the advantages of a capitalist economy geared to consumer markets.

made possible spin-offs and cross-fertilisation that were inconceivable in the Communist world.

In January 1983, *Time* magazine gave the PC its 'man of the year' accolade – the first time in fifty-five years that a non-human had been chosen. According to *Time*: 'The "information revolution" that futurists have long predicted has arrived, bringing with it the promise of dramatic changes in the way people live and work, perhaps even in the way they think. America will never be the same again.' *Time* also quoted the Austrian chancellor, Bruno Kreisky: 'What networks of railroads, highways and canals were in another age, networks of telecommunications, information and computerization . . . are today.'[37]

Once again, the Cold War military played a crucial role in the genesis of information networks. The Pentagon's Advanced Research Projects Agency (ARPA) was established after the Sputnik furore of 1957 in order to generate long-term technological programmes. One of these projects was to connect the computers of ARPA's participating institutions all over the United States. The challenges were enormous. Linking each computer to all the others by dedicated long-distance phone lines would generate astronomic bills. In any

37 Statistics and quotations from *Time*, 3 January. 1983, 4.

case, their various software systems were horrendously incompatible. So the Arpanet designer, Lawrence G. Roberts, developed the 'packet-switching' method, whereby each message was broken up into small packets and sent along the best available route to be reassembled at its destination. The network was a series of nodes, each with a minicomputer to receive, transmit, and harmonise the software. By the end of 1969, four nodes were operational, but in September 1973 forty nodes were handling 2.9 million packets a day. A public demonstration of the system at an international computer conference in Washington, DC, in October 1972 put computer networking on the map.[38]

During the 1980s, other networks were developed by government organisations such as NASA, consortia of colleges, and commercial providers. In 1983, ARPA established a set of 'protocols' enabling the various networks to interact, and this marked the beginning of the Internet – used by individuals and organisations to send electronic mail and to create sites of information. It took time to make this uncatalogued mass of electronic sites accessible. The most important innovation was the World Wide Web, spun off by a British researcher, Tim Berners-Lee, from the system he developed in 1989 for CERN, the High-Energy Physics Laboratory in Geneva. This allowed users to move from a word or phrase highlighted on the screen (hypertext) to related information on computers all over the world. The Web made the Net user-friendly for the post-Cold War era of globalisation.

The 'information society' and the end of the Cold War

For all their novelties, computers were a part of a familiar correlation in human history between knowledge and power. In other words, the capacity of governments had grown in proportion to the information at their command – about both their subjects and their enemies. As sociologist Anthony Giddens has observed, '*all* states have been information societies'.[39] The impetus given to communications and computing by the American national security state during the Cold War fits this pattern. Furthermore, the information society was, in large part, an offshoot of capitalism. Information became a commodity, to be packaged and sold like toothpaste or automobiles – whether to big

38 Lawrence G. Roberts, 'The Arpanet and Computer Networks', in Adele Goldberg (ed.), *A History of Personal Workstations* (New York: ACM Press, 1988), 152. See generally the review essay by Roy Rosenzweig, 'Wizards, Bureaucrats, Warriors, and Hackers: Writing the History of the Internet', *American Historical Review*, 103 (1998), 1530–52.

39 Anthony Giddens, *The Nation-State and Violence: Volume Two of a Contemporary Critique of Historical Materialism* (Cambridge: Polity Press, 1985), 178.

corporations in the early days of mainframe computing, or to the ordinary consumer when the PC came of age. Whatever the talk of its global implications, the information revolution had most effect on the capitalist West, on the United States and its Cold War allies.

In computers, the United States resisted early European challenges and maintained a dominant position, thanks especially to the global reach of IBM. In 1987, American machines commanded 60 per cent of the West European market.[40] In semiconductors, too, the United States sustained a huge lead. Its share of the world market was 61 per cent in 1979. Among the also-rans, Japan's share was 26 per cent – double that of all of Western Europe – thanks to a mixture of innovation, government support, and protectionism.[41] Only near the end of the Cold War, in the late 1980s, did Japan overtake the United States in the world market for semiconductors.

From the point of view of *production*, therefore, computers and semiconductors were part of a familiar story of national industrial rivalry among the world's advanced states. From the perspective of *application*, however, these new technologies connected countries rather than dividing them. Together with innovations in telecommunications, such as satellites and optical fibres, they made possible the integration of the world's leading developed nations, giving capitalism a new dynamism and internationalism after the stagflation of the 1970s and the decline of the old rust-belt heavy industries. Nowhere was this more evident than in financial services, where American multinationals developed their own global networks. At the forefront was Citicorp, which ran the largest private network in the world, linking offices in ninety-four countries, transmitting 800,000 calls a month by 1985, and allowing the company to trade $200 billion each day in foreign-exchange markets.[42] Walter Wriston, Citicorp's chairman, claimed that 'the information standard has replaced the gold standard as the basis of world finance'.[43]

Traditionally, markets were made by personal deals. This practice became institutionalised in the great stock exchanges and currency markets of the world's leading cities. But the information revolution began to challenge the practice of face-to-face capitalism. In 1971, the National Association of Securities Dealers Automated Quotations (NASDAQ) was established using

40 Flamm, *Creating the Computer*, 168.

41 Figures from Braun and MacDonald, *Revolution in Miniature*, 153.

42 Barney Warf, 'Telecommunications and the Globalization of Financial Services', *Professional Geographer*, 41 (1989), 261–62.

43 Quoted in Adrian Hamilton, *The Financial Revolution: The Big Bang Worldwide* (New York: Viking, 1986), 30.

20,000 miles of leased phone lines to link subscriber terminals to a central computing system which recorded prices, deals, and other information. By 1985, 120,000 terminals were connected. With 16 billion shares listed, at a total value of around $200 billion, NASDAQ had become the third-largest stock exchange in the world, behind New York and Tokyo.[44] Computerised networks spread to other financial markets, including futures and foreign exchange, expedited by deregulation during the 1970s and 1980s. The new technologies also facilitated 24-hour trading, with the three major centres – Tokyo, London, and New York – occupying time zones that, between them, straddled the whole day.

The information revolution, therefore, lay at the heart of global capitalism's regeneration in the 1980s. This posed an acute problem for the Soviet Union and its allies. Their leaderships understood that information was power: through the appliance of their own science and through stealing it from the West, they had kept up in the arms and space races during the first half of the Cold War. But information is also deeply subversive, which is why these controlled polities insulated scientists and technologists from the rest of society, thereby denying their economies the numerous, if often serendipitous, spin-offs. It also meant that they failed to reap the benefits from information for wealth creation. By the 1980s, this had become a critical problem for the Soviet bloc.

In 1950, S. A. Lebedev produced MESM, the first electronic stored-program digital computer in continental Europe. By the early 1960s, the Soviets had manufactured about 250 second-generation versions, and a third generation started coming on stream in the mid-1970s.[45] Like Western Europe, the Soviet Union was thereafter unable to keep up technically with the Americans; unlike them, however, it did not enjoy easy access to US high technology, most of which was tightly controlled under Cold War legislation. A report to the Central Committee of the Communist Party of the Soviet Union in October 1955 warned that 'more than 200 large universal electronic computing machines are currently in operation in the United States, while in our own country, there are only three computers'.[46] Industrial espionage helped, but the result was a derivative technology, and one that lagged well behind the United States. Most Soviet mainframe designs since the 1960s were based on pirated IBM 360

44 *Ibid.*, 42–45.

45 Graham, *Science in Russia and the Soviet Union*, 256; Amann and Cooper (eds.), *Industrial Innovation in the Soviet Union*, 214–17.

46 Slava Gerovitch, *From Newspeak to Cyberspeak: A History of Soviet Cybernetics* (Cambridge, MA: MIT Press, 2002), 193.

architecture. In line with other Soviet innovations, moreover, the priority was military applications, followed by computer systems for government ministries. Networks, modelled on the Arpanet, were also developed, both for the government and, in the case of the Akademset, for Soviet R&D work.[47] But the weakness of the Soviet economy militated against PC development. And the West Coast computer hobby culture that nurtured entrepreneurs such as Steve Jobs and Bill Gates was inconceivable in the Soviet Union.

In microcomputers and microelectronics generally, the Soviets were inferior to their own client states such as Czechoslovakia and East Germany. Yet even Eastern Europe's pirated products did not compare with authentic Western versions. In 1986, the creator of the Czech Ondra micro lamented the growing penetration of Western PCs:

> With these computers comes not only technology but also ideology ... Children might soon begin to believe that Western technology represents the peak and our technology is obsolete and bad ... [I]n 10 years' time it will be too late to change our children. By then they will want to change us.[48]

Thus, the PC and communications revolutions posed a double challenge to the Soviet bloc – economic and ideological. Historian Charles Maier has described the East German economy in the late 1980s as being in 'a race between computers and collapse'.[49] Moscow's Twelfth Five-Year Plan of 1985 envisaged 1.3 million PCs in Soviet schoolrooms by 1995. But the Americans already had 3 million in 1985 and, in any case, the main Soviet PC, the Agat, was an inferior version of the outdated Apple II.[50] Mikhail Gorbachev, the new Soviet leader from March 1985, was keenly sensitive to these problems. *Informatizatsiia* (crudely, informationisation) became a buzzword of his new era. His American interlocutor, Secretary of State George Shultz, played on this concern by periodically giving him admonitory tutorials about how the rest of the world was moving from 'the industrial age to the information age' and how only open societies could accomplish this vital transition.[51]

Had the Soviet bloc remained a closed system based on coal, steel, and heavy industry, it might have staggered on. But insulation was impossible.

47 Richard W. Judy, 'Computing in the USSR: A Comment', *Soviet Economy*, 2 (1986), 355–67.
48 Quoted in Karen Dawisha, *Eastern Europe, Gorbachev and Reform: The Great Challenge*, 2nd ed. (Cambridge: Cambridge University Press, 1990), 160.
49 Charles S. Maier, *Dissolution: The Crisis of Communism and the End of East Germany* (Princeton, NJ: Princeton University Press, 1997), 73.
50 Judy, 'Soviet Computing', 362–63.
51 George P. Shultz, *Turmoil and Triumph: My Years as Secretary of State* (New York: Charles Scribners' Sons, 1993), 586–91, 891–93.

Growth in the 1970s had been funded by Western loans. The result was a soaring foreign debt, which exceeded $95 billion by 1988, and this had to be repaid or at least serviced by foreign trade.[52] Yet Soviet bloc competitiveness was falling further behind, as North America and Western Europe transcended their 1970s crisis of capitalism by cutting heavy industry, expanding services, and developing new information technologies.[53] Communism now had to face the same structural problems of outdated heavy industry in a globalising market, within a system far more ossified in its command management ideology.

At the same time, the communications revolution in phones and faxes, television and radio, made it ever harder to insulate Soviet bloc citizens from evidence of the failure of their regimes and of the lifestyles of the West. The Iron Curtain could block the movement of people, but it was no barrier to the air waves that carried Western radio and television across Central and Eastern Europe. The BBC, Voice of America, Deutsche Welle, and especially Radio Free Europe were all widely heard in the East. Most of East Germany could receive West German television, likewise Austrian television in Hungary, while the Czechs could watch transmissions from both. By the 1980s, television ownership was general, and official jamming had become another casualty of détente with the West. The words and images of these programmes, not to mention the commercials, delivered a damning verdict on the Communist system. And in 1989, unlike the crises of 1956 and 1968, this information could no longer be controlled, thanks to that all-purpose weapon of revolution – the transistor radio. News of the reforms in Poland and Hungary quickly spread across the bloc, especially the opening of the Hungarian–Austrian border, which acted as a magnet for East Germans seeking their right of citizenship in the Federal Republic. And news of the fall of the Wall in November 1989 galvanised protest in Czechoslovakia and Romania. Of course, people power in the streets and divisions within the Communist leaderships were key factors in the revolutions of 1989.[54] But the speed of events owed much to the multiplier effect of modern technology. It has been aptly observed that 1989 was 'as much the triumph of communication as the failure of Communism'.[55]

52 Dawisha, *Eastern Europe, Gorbachev and Reform*, 118, 169.

53 For the revitalisation of Western and US capitalism in the 1980s, see Giovanni Arrighi's chapter in this volume.

54 See Jacques Lévesque's and Helga Haftendorn's chapters in this volume.

55 James Eberle, 'Understanding the Revolutions in Eastern Europe: A British Perspective and Prospective', in Gwyn Prins (ed.), *Spring in Winter: The 1989 Revolutions* (Manchester: Manchester University Press, 1990), 197.

Science and the dynamics of the Cold War

The Cold War is rightly identified as the nuclear age. Yet many other technologies played their part, usually stimulated and financed in their crucial early stages by military imperatives. The development of transistors miniaturised electronic components, making possible terrestrial satellites and economical computers. Satellites were vital for Cold War intelligence and also for national and international communications, both through television and phones. Computers were essential for directing complex weapons systems and managing masses of information. And computer networks linked by modern communications systems became fundamental to national security and national wealth creation.

In all these areas the United States led the way, with vast infusions of Cold War funding. The Soviet Union usually kept up: its military-industrial complex was more heavily funded and also privileged over consumer demand. The American military system, however, was integrated symbiotically into a dynamic civilian economy geared to consumer demand. Government funding, though often essential in the start-up phase, was soon eclipsed, as new technologies were refined outside the military sector and then adapted anew for Cold War use – the personal computer being a classic example. The computer revolution also brought to crisis point the information deficit in Soviet society. Both superpowers controlled and directed information – social, scientific, and technological – during the Cold War, but the Soviet Union was much more regimented than the United States. In the short term, that kept it going, but eventually the 'iron curtain' between its military system, on the one hand, and its civilian economy and society, on the other, was a significant factor in the Soviet collapse.[56]

56 For this use of the term 'iron curtain', see Gerovitch, *From Newspeak to Cyberspeak*, 141.

Wirtschafts- und Währungsunion: politische Zwänge im Konflikt mit ökonomischen Regeln (Stuttgart: Deutsche Verlags-Anstalt, 1998), is very instructive. An overview of the intra-German aspects of unification is given in Wolfgang Jäger, *Die Überwindung der Teilung: der innerdeutsche Prozeß der Vereinigung 1989/90* (Stuttgart: Deutsche Verlags-Anstalt, 1998), while the international aspects are dealt with by Werner Weidenfeld, *Außenpolitik für die Deutsche Einheit: die Entscheidungsjahre 1989/90* (Stuttgart: Deutsche Verlags-Anstalt, 1999).

A number of memoirs add detail and special flavor. Very valuable are the works of two close associates of Helmut Kohl. In Wolfgang Schäuble, *Der Vertrag: wie ich über die deutsche Einheit verhandelte* (Stuttgart: Deutsche Verlags-Anstalt, 1991), the chancellor's former chief of staff gives an insider's account on negotiating with his counterparts from the German Democratic Republic (GDR) on the unification treaty, while Horst Teltschik, Kohl's foreign-policy aide, tells the story of the international negotiations on unification and details many little-known facts: Teltschik, *329 Tage: Innenansichten der Einigung* (Berlin: Siedler, 1991). Unfortunately, neither Kohl's memoirs nor the memoirs of Foreign Minister Genscher meet strict historical standards. Helmut Kohl in his *Erinnerungen 1982–1990* (Munich: Droemer, 2005) remembers events up to March 1990 but frames them according to his political predilections. Hans-Dietrich Genscher's *Erinnerungen* (Berlin: Siedler, 1995) suffers from a certain vagueness intended not to offend people who were still alive.

As the above works have been written by West Germans, they emphasize the Federal Republic's perspective. They should be complemented by publications focusing on the GDR. Three works stand out: Hans-Hermann Hertle, *Der Fall der Mauer: die unbeabsichtigte Selbstauflösung des SED-Staates* (Opladen: Westdeutscher Verlag, 1996) uses recently opened SED party files. In Elizabeth Pond, *Beyond the Wall: Germany's Road to Unification* (Washington, DC: Brookings Institution Press, 1993), a Berlin-based American journalist tells the story of German reunification and gives many details on the domestic situation in the two German states. The most analytic work is Charles S. Maier, *Dissolution: The Crisis of Communism and the End of East Germany* (Princeton, NJ: Princeton University Press, 1997). In it, the renowned Harvard historian analyzes the economic and political collapse of the GDR and puts it into the context of the Cold War and its demise. There is no authentic account by a GDR scholar. Heinrich Bortfeld, *Washington-Bonn-Berlin: die USA und die deutsche Einheit* (Bonn: Bouvier, 1993), is a solid work by an East German historian, but emulates Western perspectives, while Ulrich Albrecht, *Die Abwicklung der DDR: die "2+4-Verhandlungen." Ein Insiderbericht* (Opladen: Westdeutscher Verlag, 1992), a West Berlin political scientist who participated in the process of reunification as head of the East German foreign office's planning staff, gives a rather bitter account of the end of the GDR.

The memoirs of the leading American political figures at the time should also be consulted. President George H. W. Bush gives a joint account together with his national security adviser, Brent Scowcroft, *A World Transformed* (New York: Random House, 1998), while his secretary of state, James A. Baker III, has titled his autobiography *The Politics of Diplomacy: Revolution, War and Peace, 1989–1992* (New York: G. P. Putnam's Sons, 1995). Another report comes from two National Security Council staffers, Philip Zelikow and Condoleezza Rice, *Germany Unified and Europe Transformed: A Study in Statecraft* (Cambridge, MA: Harvard University Press, 1995). All three works base their account on the same sources and use an internal State Department historical study drafted by Robert Zoellick. Bush and Scowcroft are most explicit on their talks with other leaders; Baker

focuses on the 2+4 talks, relations with Soviet foreign minister Eduard Shevardnadze, and the other crises American foreign-policy officials had to attend to at the time (e.g., Lithuania and the Gulf War); while Zelikow and Rice span the presidential, National Security Council, and State Department level and give details on internal deliberations.

For a British view, the reader is referred to the very personal but revealing memoirs of the then prime minister: Margaret Thatcher, *The Downing Street Years* (London: HarperCollins, 1993). The best French viewpoint with special emphasis on Mitterrand appears in Frédéric Bozo, *Mitterrand: la fin de la guerre froide et l'unification allemande. De Yalta à Maastricht* (Paris: Odile Jacob, 2005; English translation, Berghahn Books, 2009). A perspective on Soviet positions is offered by Hannes Adomeit, *Imperial Overstretch: Germany in Soviet Policy from Stalin to Gorbachev. An Analysis based on New Archival Evidence, Memoirs, Interviews* (Baden-Baden: Nomos, 1998).

To put reunification into the context of German post-World War II history, the reader should refer to Helga Haftendorn, *Coming of Age: German Foreign Policy since 1945* (Lanham, MD: Rowman & Littlefield, 2006), which gives an overview of German foreign policy from 1945 to 2005 and is based on a large body of documents.

See also section 15 of this bibliographical essay.

17. The collapse of the Soviet Union, 1990–1991

For bibliographical entries on the collapse of the Soviet Union, see section 12.

18. Science, technology, and the Cold War

On the overall patterns of big science, see Peter Galison and Bruce Hevly (eds.), *Big Science: The Growth of Large-Scale Research* (Stanford, CA: Stanford University Press, 1992), Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial Complex at MIT and Stanford* (New York: Columbia University Press, 1993), a useful account ranging well beyond these two pioneering universities, and, for international comparisons, Etel Solingen (ed.), *Scientists and the State: Domestic Structures and the International Context* (Ann Arbor, MI: University of Michigan Press, 1994). On the Soviet side, see Loren R. Graham, *Science in Russia and the Soviet Union: A Short History* (Cambridge: Cambridge University Press, 1993), Nikolai Krementsov, *Stalinist Science* (Princeton, NJ: Princeton University Press, 1997), Paul Josephson, "'Projects of the Century' in Soviet History: Large-Scale Technologies from Lenin to Gorbachev," *Technology and Culture*, 36 (1995), 519–59, and David Holloway, *Stalin and the Bomb: The Soviet Union and Atomic Energy* (New Haven, CT: Yale University Press, 1994), which is invaluable on Soviet science and technology in general. More generally, see two related volumes of essays: Ronald Amann, Julian Cooper, and R. W. Davies (eds.), *The Technological Level of Soviet Industry* (New Haven, CT: Yale University Press, 1977), and Ronald Amann and Julian Cooper (eds.), *Industrial Innovation in the Soviet Union* (New Haven, CT: Yale University Press, 1982), though the data in each are somewhat outdated. For fuller bibliographical information on the USSR, in both English and Russian, consult the Massachusetts Institute of Technology's excellent "Virtual Guide to the History of Russian Science and

Technology" at web.mit.edu/slava/guide/. For the British story, see the essays in Robert Bud and Philip Gummett (eds.), *Cold War, Hot Science: Applied Research in Britain's Defence Laboratories, 1945–1990* (London: Harwood, 1999).

For semiconductors, see Robert Buderi, *The Invention That Changed the World* (New York: Touchstone, 1996), on wartime radar and its multitudinous spinoffs, Ernest Braun and Stuart MacDonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics*, 2nd ed. (Cambridge: Cambridge University Press, 1982), a good introduction to the science and the history, and Michael Riordan and Lillian Hoddesdon, *Crystal Fire: The Birth of the Information Age* (New York: W. W. Norton, 1997), an excellent overview of microelectronics from the transistor to the chip, based on key archives. Two important articles on the role of the military are Paul Forman, "Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940–1960," *Historical Studies in the Physical and Biological Sciences*, 18 (1987), 149–229, and Thomas J. Misa, "Military Needs, Commercial Realities, and the Development of the Transistor, 1948–1958," in Merritt Roe Smith (ed.), *Military Enterprise and Technological Change* (Cambridge, MA: MIT Press, 1985), 253–87.

On satellites, Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), remains an essential introduction to the space race, but see also Matthew J. von Bencke, *The Politics of Space: A History of US–Soviet/Russian Competition and Cooperation in Space* (Boulder, CO: Westview, 1997). Günter Paul, *The Satellite Spin-Off: The Achievements of Space Flight*, transl. by Alan Lacy and Barbara Lacy (New York: Robert B. Luce, 1975), is useful on the wider implications, and Robert W. Campbell, "Satellite Communications in the USSR," *Soviet Economy*, 1 (1985), 313–39, is a good introduction on the Soviet side. For the impact on telecommunications, see Robert W. Campbell, *Soviet and Post-Soviet Telecommunications: An Industry under Reform* (Boulder, CO: Westview, 1995), a rare and very useful study, and John Bray, *The Communications Miracle: The Telecommunication Pioneers from Morse to the Information Superhighway* (London: Plenum Press, 1995), a good overview of the changing technologies.

An outstanding introduction to computers is Martin Campbell-Kelly and William Aspray. *Computer: A History of the Information Machine* (New York: Basic Books, 1996). See also Kenneth Flamm, *Creating the Computer: Government, Industry, and High Technology* (Washington, DC: Brookings Institution Press, 1988), and Paul Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, MA: MIT Press, 1996). For the Soviet side, see Richard W. Judy, "Computing in the USSR: A Comment," *Soviet Economy*, 2 (1986), 355–67, and Slava Gerovitch, *From Newspeak to Cyberspeak: A History of Soviet Cybernetics* (Cambridge, MA: MIT Press, 2002) – like Edwards on the United States, an interesting study of ideology and discourse. On SAGE, see the special issue of *Annals of the History of Computing*, 5, 4 (October 1983), 319–403. For computer networks, consult the autobiographical piece by Lawrence G. Roberts, "The Arpanet and Computer Networks," in Adele Goldberg (ed.), *A History of Personal Workstations* (New York: ACM Press, 1988), 143–67, and, more generally, Katie Hafner and Matthew Lyon, *Where Wizards Stay Up Late: The Origins of the Internet* (New York: Simon & Schuster, 1996). See generally the review essay by Roy Rosenzweig, "Wizards, Bureaucrats, Warriors, and Hackers: Writing the History of the Internet," *American Historical Review*, 103 (1998), 1530–52.

Paul Maddrell, *Spying on Science: Western Intelligence in Divided Germany, 1945–1961* (Oxford: Oxford University Press, 2006), is a pioneering analysis of scientific intelligence, using East German sources. Some of the implications of technological crisis for the end of the Cold War are explored in Loren R. Graham, *The Ghost of the Executed Engineer: Technology and the Fall of the Soviet Union* (Cambridge, MA: Harvard University Press, 1993), which uses the story of Peter Palchinsky as a parable of Soviet technological failure, Charles S. Maier, *Dissolution: The Crisis of Communism and the End of East Germany* (Princeton, NJ: Princeton University Press, 1997), especially chapter 2 on the "race between computers and collapse," and Tomasz Goban-Klas and Pal Kolstø, "East European Mass Media: The Soviet Role," in Odd Arne Westad, Sven Holtsmark, and Iver B. Neumann (eds.), *The Soviet Union in Eastern Europe, 1945–1989* (New York: St. Martin's Press, 1994), 110–36, on the impact of information.

19. Transnational organizations and the Cold War

The activities of the Pugwash Conferences on Science and International Affairs have been documented by its founding member and longtime head, Joseph Rotblat, in *Scientists in the Quest for Peace: A History of the Pugwash Conferences* (Cambridge: MIT Press, 1972), in publications of the organization's proceedings and in accounts drawing on Pugwash archives and interviews with participants. See Sandra Ionno Butcher, "The Origins of the Russell–Einstein Manifesto," Pugwash History Series, no. 1 (May 2005), and Bernd W. Kubbig, "Communicators in the Cold War: The Pugwash Conferences, the US–Soviet Study Group and the ABM Treaty," PRIF Reports, 44, Peace Research Institute Frankfurt (Frankfurt am Main, Germany, October 1996). Russian accounts include Yu. A. Ryzhov and M. A. Lebedev, "RAS Scientists in the Pugwash Movement," *Herald of the Russian Academy of Sciences*, 75, 3 (2005), 271–77.

The scholarly literature on transnational relations began in Germany with an article by Karl Kaiser in *Politische Vierteljahresschrift*, 1 (1969), and in the United States with a special issue of the journal *International Organization*, later published as Robert O. Keohane and Joseph S. Nye, Jr. (eds.), *Transnational Relations and World Politics* (Cambridge, MA: Harvard University Press, 1972). It included a chapter by Lawrence Scheinman on the control of nuclear energy, with a brief discussion of Pugwash. Interest in transnational relations revived in the 1990s, again following the lead of the activists themselves. See Thomas Risse-Kappen, "Ideas Do Not Float Freely: Transnational Coalitions, Domestic Structures, and the End of the Cold War," *International Organization*, 48, 2 (Spring 1994), 185–214; Thomas Risse-Kappen, (ed.), *Bringing Transnational Relations Back In: Non-State Actors, Domestic Structures and International Institutions* (Cambridge: Cambridge University Press, 1995), with chapters by Patricia Chilton on transnational contacts between human rights activists in Eastern and Western Europe and by Matthew Evangelista on transnational coalitions between Soviet and Western scientists and physicians working on issues of disarmament and arms control; Evangelista's *Unarmed Forces: The Transnational Movement to End the Cold War* (Ithaca, NY: Cornell University Press, 1999); Emanuel Adler, "The Emergence of Cooperation: National Epistemic Communities and the International Evolution of the Idea of Nuclear Arms Control," *International Organization*, 46, 1 (1992),